

Covalent adaptable networks – a recyclable alternative to thermosets

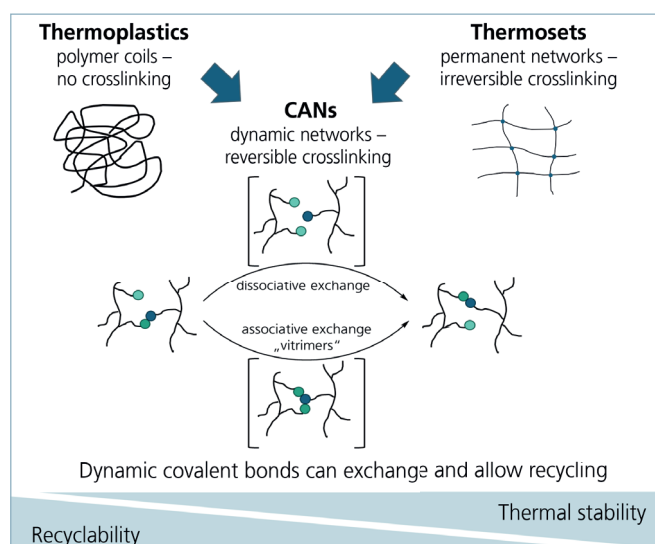
Covalent adaptable networks (CANs)

Thermosets are widely used in high-performance applications such as electronic components, automotive parts and adhesives where durability and heat resistance are required. They are characterized by high mechanical strength, thermal stability, and chemical resistance due to their permanently crosslinked molecular structure. However, these crosslinks prevent simple reprocessing or reshaping of the material, which complicates recovery and reuse. This recycling challenge poses an environmental threat, as thermoset products frequently end up in landfills, contributing to the accumulation of plastic waste.

Covalent adaptable networks (CANs) are an innovative alternative to conventional thermosets because they combine the mechanical strength and thermal stability of thermosets with the ability to be reprocessed or reshaped. They contain dynamic covalent bonds which can be activated with an external stimulus and allow recycling, repairing and reprocessing. CANs combine the reprocessability of thermoplastics with the mechanical strength and thermal stability of thermosets. In associative CANs, also called vitrimers, dynamic covalent bonds exchange through a bond-exchange mechanism without reducing the overall crosslink density. In dissociative CANs, bonds break before new ones form, temporarily lowering crosslink density and leading to a reduction in the viscosity.

Synthesis, processing and characterization of CANs and vitrimers

At Fraunhofer ICT, we focus on the synthesis of both covalent adaptable networks (CANs) and vitrimers, as well as the design and preparation of tailored precursor molecules required for their formation.



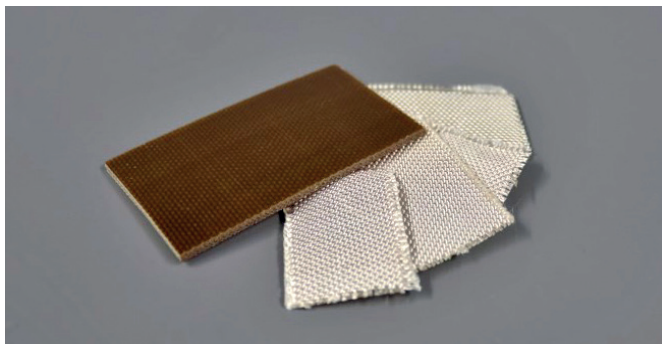
Properties of thermoplastics and thermosets and their combination in CANs.

In addition, we develop and synthesize additives specifically designed to optimize the properties and performance of dynamic polymer networks. Our research activities extend beyond synthesis to the comprehensive characterization and evaluation of these materials, in particular their viscoelastic behavior. In this context, stress relaxation experiments are a central tool, allowing us to analyze network dynamics and assess the reprocessability under various thermal and mechanical conditions.

In addition, we manufacture fiber-reinforced composites based on CANs and vitrimers. For laboratory-scale material testing, we employ wet pressing techniques to manufacture composite plates with controlled fiber content and orientation.



Virgin vitrimer based on disulfide bonds (left), ground vitrimer particles (middle) and recycled vitrimer via hot pressing (right).



Fibre-reinforced vitrimer composite based on disulfide bonds (left) and natural fibers recovered in a chemical recycling process.

Mechanical reprocessing

Due to the dynamic bonds CANs and vitrimers have the potential for mechanical recycling. Our work focuses on assessing their repairability and reprocessability by mechanically grinding the materials, subsequently rejoining them through hot pressing, and evaluating the resulting mechanical and thermal properties. Furthermore, we investigate the extrusion processability of certain material systems and analyze the influence of processing parameters.

Chemical recycling

Certain CANs and vitrimers are suitable for chemical recycling due to the dynamic bonds which can undergo reversible exchange reactions with small molecules in an appropriate solvent under appropriate conditions. This molecular adaptability allows the complete dissolution of the polymer networks. At Fraunhofer ICT, we actively investigate chemical recycling strategies for such materials, including the recovery of fibers – especially carbon fibers – from fiber-reinforced composites. We analyze the properties of both the reclaimed fibers and the regenerated matrix, and we study their potential for repolymerization and reintegration into new composite materials. This approach enables the development of more circular material systems.

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